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Contracting Officer  
George C. Marshall Space Flight Center  
Marshall Space Flight Center, Alabama 35812

Subject: Final Report NAS8-32689 (Revised August 6, 1980)

Dear Sir:

Two revised copies of the final report on the Molecular Wake Shield Gas Analyzer Study Contract NAS8-32689 are enclosed for your review and approval.

Sincerely,

John H. Hoffman  
Principal Investigator

JHH:jr

Enclosures: 2 copies Final Report  
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MOLECULAR WAKE SHIELD GAS ANALYZER

FINAL REPORT  
(Revision A)

For Contract NAS8-32689

Prepared for

George C. Marshall Space Flight Center  
Marshall Space Flight Center, Alabama 35812

by

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## I. INTRODUCTION

This report covers work done on Contract No. NAS8-32689 from Marshall Space Flight Center, in a study of concepts and techniques for measuring and characterizing the ultra high vacuum in the wake of an orbiting spacecraft. The instrument which was proposed for the study is a high sensitivity mass spectrometer that contains a double mass analyzer consisting of an open source miniature magnetic sector field neutral gas analyzer and an identical ion analyzer. These are configured to detect and identify gas and ion species of hydrogen, helium, nitrogen, oxygen, nitric oxide and carbon dioxide and any other gas or ion species in the 1 to 46 amu mass range. This range covers the normal atmospheric constituents. The sensitivity of the instrument is sufficient to measure ambient gases and ions with a particle density of the order of one per cc. A chemical pump, or getter, is mounted near the entrance aperture of the neutral gas analyzer which integrates the adsorption of ambient gases for a selectable period of time for subsequent release and analysis. The sensitivity stated above is realizable for all but rare gases using this technique. Rare gas sensitivity is one order of magnitude less. Table I is a summary of instrument parameters.

The instrument was being developed to fly on several shuttle flights when space would become available to determine the ambient gas and ion species and their concentrations existing in the wake of a vehicle flying at orbital speeds if direct outgassing molecules from the vehicle are prevented from entering the mass spectrometer. The instrument would be flown in the wake of a free flyer and in the shuttle's own wake. Data obtained from these flights would be useful in designing and implementing the large Molecular Wake Shield Space Vacuum Facility.

TABLE I  
INSTRUMENT PARAMETER SUMMARY

**Performance Parameters:**

Measurement: Ambient Neutral gas and ion concentrations in wake of orbiting spacecrafts

Mass Range: Low channel: 1 to 4 amu  
High channel: 12 to 46 amu

Sensitivity: Neutrals: ~10 per cc  
with getter-1 per cc  
Ions: <1 per cc

Dynamic Range:  $3 \times 10^6$

Resolution: Peak to valley ratio >100 at mass 44

Mass Scan: Peak to peak stepping  
Dwell time adjustable (nominally 6 sec)

Instrument: Magnetic sector field mass spectrometer with dual entrance apertures and mass analyzers for ambient neutral gas and ion measurements.  
Getter to integrate ambient gas absorption for subsequent release and analysis.

Volume, weight and power: TBD

Command and telemetry interface: TBD

Mounting: Instrument must be located behind orbiting vehicle with entrance apertures orientable in both the ram and wake directions.  
Ion source must operate at low temperature. (<0°C)

Instruments similar to that studied here were flown to the moon on Apollos 15, 16, and 17 to study the composition of the lunar atmosphere. On the first two flights, the instrument was attached to a retractable boom mounted on the Apollo Command and Service Module (CSM). The Apollo 17 instrument was deployed on the lunar surface as part of the ALSEP. The ion mass analyzer is patterned after those flown on the ISIS-IJ, AE-C and D and DE-A spacecrafts.

Chemical getter pumps were used extensively in the mass spectrometer instrument flown on the Pioneer Venus mission in December, 1978, to measure the composition of the lower Venus atmosphere.

Absolute calibration of the lunar instruments was done in the NASA Langley Research Center molecular beam chamber using known beam fluxes of Ar, CO<sub>2</sub>, CO, Kr, Ne, N<sub>2</sub> and H<sub>2</sub>. Instrument packages were designed to withstand the rather severe lunar environment. The lunar orbital instruments operated well throughout the mission lifetimes. The Apollo 17 instrument provided good data for over 10 lunations. From this sizable data base, information on the identities and variations of the lunar atmospheric constituents was obtained.

The ISIS and AE ion mass spectrometers operated successfully for periods of 9 and 5 years respectively. Significant results from all these experiments can be found in the references.

## II. APPROACH

The instrument developed to perform the measurements discussed in Section I is a dual analyzer miniature magnetic sector field mass spectrometer. Two entrance apertures are provided which lead into identical mass analyzers. Gas molecules enter one aperture directly into an ion source. Ambient ions are biased out of this entrance. While the operation of the ion source is

essentially as an open source mass spectrometer, there are wall effects from the electrodes of the ion source itself which in effect make it act like a partially closed source. However, these can be accounted for during calibration, as was done for the Lunar instrument using the NASA LRC molecular beam chamber.

A chemical getter is mounted in an appendage to this entrance aperture to adsorb ambient gases over a selectable period of time for subsequent release by heating of the getter. The released gases are analyzed in the same manner as directly incoming ambient gas molecules. The advantage of the getter is as a storage or accumulation mechanism for ambient gases. When released, the ambient gas density in the ion source will be enhanced by one to two orders of magnitude, thereby increasing the instrument sensitivity by this amount.

In order to reduce local outgassing to an acceptable level relative to the expected ambient gas densities, the ion source must operate at a temperature of 0°C or below. This can be accomplished by appropriate shielding from the spacecraft, sun and earth's albedo. Gas molecules entering the aperture containing the ion source are ionized by electron bombardment using a hot tungsten filament or a cold electron emitter. Ions enter the other aperture directly into the mass analyzer. Neutral particles may enter this aperture but will not be detected because there is no ionization mechanism here.

Both mass analyzers operate in an identical manner. The ions formed in the source or entering the ion aperture are each collimated into a beam and directed through identical magnetic fields of nominally 0.4T. Two allowed beam trajectories through each magnet define the location of two image points. This permits two mass ranges to be scanned simultaneously, namely 1 to 4 and 12 to 46 amu. The advantage of the dual collector analyzer

lies in the fact that a wide mass range may be covered by a relatively narrow voltage excursion which facilitates power supply design and provides a more uniform response over the mass spectrum.

Both analyzers are operated by common electronics. Scanning of the mass spectrum is accomplished by a high voltage controllable power supply. Voltage variation is accomplished by a stepping sequencer (a ladder network) which permits scan of the entire mass range or the selection of specific mass peaks which may be monitored continuously or in a commandable or pre-set sequence. Dwell time per mass peak is also selectable. The amount of flexibility and complexity of the scan modes can be adjusted to be consistent with the specific objectives and capabilities of the mission on which the instrument is flown.

Each ion detector system employs electron multipliers and pulse counting circuitry with a maximum counting rate of 40 MHz. The number of ion pulse counts accumulated during each ion accelerating voltage step (nominally several seconds-but easily adjustable) is stored in a 24-bit accumulator and read out when interrogated by the data handling system. With this system a dynamic range of more than 6 decades is achieved. If the telemetry bandwidth is limited, the 24-bit data word can be compressed into a 10-bit floating point (base 2) word before being presented to the data handling system. Electron multiplier gains and discriminator threshold levels are adjustable by command.

The mass analyzer sensitivities are sufficient to detect and identify gas species at a particle density of the order of 1/cc for most gases in the 1 to 46 amu mass range when the getter technique is employed. Without the use of the getter, as for rare gases, the sensitivity will be decreased by a factor of 10. Sensitivity to ambient ions is 1/cc. Dynamic range is

approximately  $3 \times 10^6$ , and mass resolution is adjusted to yield a peak to valley ratio of greater than 100 over the entire mass range.

Housekeeping analog outputs monitor a number of instrument parameters (supply voltages, filament or electron emitter currents, and several temperatures).

Instruments of this type are typically mounted on a baseplate that bisects the package. The mass analyzers are located on one side with the electronics package on the other in a thermally controlled enclosure.

The mounting device of the instrument should have the capability of orienting the entrance aperture into the ram and wake directions behind the vehicle whose wake vacuum it is measuring. This would be accomplished behind the shuttle by using the remote manipulator unit, but a swivel mount would be required if making measurements behind a free flying satellite.

### III. ANALYSES OF TEST RESULTS FROM PREVIOUSLY FLOWN MASS SPECTROMETERS

The instruments upon which the neutral gas analyzer is based were flown to the moon on Apollos 15, 16 and 17 to study the composition of the lunar atmosphere. On the first two flights the mass spectrometer was mounted on an extendable boom which placed the instrument 7 meters from the Service Module as it flew in lunar orbit. (Hoffman and Hodges, 1972). Several ram-wake and CSM outgassing studies were done while the instrument was in lunar orbit. It was found that although the mass spectrum showed many peaks, direct outgassing from the CSM was not observed beyond 1 meter from its surface. (The mass spectrometer entrance aperture was shielded from direct line-of-sight observation of the CSM). This means that the outgassing molecular density beyond 1 meter was sufficiently low as to form a collisionless gas beyond that point. What seemed to be observed, however, was a continual outgassing or evaporation of gases from frozen co-orbiting water and/or fuel droplets that had their origin

from the CSM. This source of gas seemed to largely disappear during trans-earth coast.

For an earth orbiting vehicle, co-orbiting gas molecules originating from the Shuttle vehicle may not be a problem either. At altitudes of 200 to 300 km such molecules will suffer collisions with ambient gas molecules and loose energy. This process should rather quickly alter the orbits of the outgassed molecules so that they will no longer form a torus along the Shuttle orbit. If this were to happen, say at higher altitudes where mean free paths become long, then the wake of the vehicle or a molecular shield would be populated with such molecules. One of the goals of the test flights of the instrument will be to determine the magnitude of this effect in earth orbit.

The Apollo 17 instrument was deployed on the lunar surface as part of the ALSEP (Hoffman, et al., 1973c, 1974b). It operated for over 10 lunations giving a large data base on the variations of several lunar constituents. These data have been used in Monte Carlo calculations (Hodges and Hoffman, 1974a) to model the lunar atmosphere. The ALSEP instrument, called LACE (Lunar Atmospheric Composition Experiment), had a measured sensitivity of 100 to 200 molecules per cc with an integration period of 0.6 sec per mass peak. By increasing the integration period by a factor of 10 and improving the analyzer ion transmission by decreasing the mass resolution from 110 to 46, the sensitivity of the proposed instrument can be improved to measure 10 molecules per cc. Employment of the getter accumulation technique will further increase the sensitivity to better than 1 molecule per cc. LACE was a triple beam instrument with a mass range that extended from 1 to 110 amu. However, the reduction of mass range to 46 amu in a dual range represents a simplification to the analyzer. Basically it would consist of only the

low and mid mass channels of the LACE instrument.

Calibration of the lunar instruments was performed at the NASA LRC molecular beam facility. A molecular beam is a stream of molecules effusing from a small aperture source into an evacuated chamber, where its direction is defined by collimating apertures. The molecular beam system used for this experiment is shown schematically in Figure 1. A high-pressure gas source (number 2, Fig. 1), measured by a rotating piston gage, is required to maintain inlet pressures from  $0.1 \cdot 10^4$  Torr, at a constant known temperature between 295 and 301 K. This known pressure is reduced from four to seven orders of magnitude through a selected porous plug into a molecular furnace (number 4, Fig. 1). From there the gas effuses through a well-defined aperture in the furnace with a cosine distribution. All but the core of this effused gas is stripped off by liquid-helium-cooled aperture surfaces, the remaining core of gas (number 9, Fig. 1) forming the molecular beam. The beam passes through a liquid-helium-temperature inner tube to the mass spectrometer inlet plenum. The porous plug used in this application was a silicate glass plug, the conductance ( $C_p$ ) of which was experimentally determined (in situ) for all test gases. For a known volume of gas attached to the porous plug in a steady-state flow condition, molecular conservation requires that

$$P(t) = P_0 e^{-C_p t/V}.$$

When the initial source pressure  $P_0$ , the pressure  $P(t)$ , volume  $V$ , and time  $t$  are known, the conductance can be determined from experimental data over a given pressure range. From these data, a mean value of conductance at 298 K was found to be  $1.18 \times 10^{-6}$  liters/sec for argon and  $1.64 \times 10^{-6}$  liters/sec for neon. Since the molecular beam flux is a function of the furnace temperature, accurate monitoring of this temperature is essential. The furnace and gas source temperatures were maintained essentially at a constant value with variations of less than 0.2 K. Therefore, errors in the temperature measurement

were considered negligible. Gas molecules, upon entering the molecular furnace, equilibrate to the wall temperature since the pressure is sufficiently low for molecular flow conditions to exist. The molecular beam effusing from the furnace aperture, at the furnace temperature, can be shown to have a flux density of

$$\Gamma_b = \frac{1}{2} \left( \frac{r_a}{l} \right)^2 \frac{C_p}{C_a} \left( \frac{2}{\pi m k T_f} \right)^{1/2} P_s \frac{\text{molecules}}{\text{cm}^2 \text{ sec}},$$

where  $C_a$  = conductance of furnace aperture, 3.4 liters/sec for argon and 4.8 liters/sec for neon at 298 K;  $C_p$  = Conductance of porous plug,  $1.18 \times 10^{-6}$  liters/sec for argon and  $1.64 \times 10^{-6}$  liters/sec for neon at 298 K;  $k$  = Boltzmann's constant;  $l$  = Distance from beam aperture to plenum inlet, 207 cm;  $m$  = mass per molecule (grams/molecule);  $P_s$  = source pressure ( $\text{dynes/cm}^2$ );  $r_a$  = furnace aperture radius, 0.33 cm;  $T_f$  = furnace temperature, 298 K; and  $\Gamma_b$  represents the number of molecules per second impinging on each square centimeter of the inlet (plenum) opening. Table II gives the comparison of source pressure, beam flux, and beam pressure.

The mass spectrometer is shown mounted in the MBS as shown in Fig. 1, where the electronic package is in the guard vacuum of the system and the inlet plenum axis is aligned with the beam axis. An externally controlled mechanical linkage was used to set the beam-plenum axis angle (equivalent to the spacecraft yaw axis) from  $0^\circ$  to  $40^\circ$  with reference to a horizontal axis perpendicular to the beam axis. Pitch angles of  $-5^\circ$ ,  $0^\circ$ , and  $+5^\circ$  with reference to a vertical axis perpendicular to the beam axis were set manually with the system open. Separate measurements were made using combinations of the three pitch angles and various yaw angles up to  $40^\circ$ . The mass spectrometer inlet was completely enclosed by a liquid-helium-temperature copper tube, an extension of the beam collimating tube, such that back-

Source pressure (psi)	Flux (mol/cm <sup>2</sup> sec)	Beam pressure <sup>a</sup> (P <sub>b</sub> ) (Torr)
<b>Argon</b>		
0.1	1.45 x 10 <sup>9</sup>	0.6 x 10 <sup>-13</sup>
0.3	4.25 x 10 <sup>9</sup>	2.9 x 10 <sup>-12</sup>
1.0	1.45 x 10 <sup>10</sup>	0.6 x 10 <sup>-12</sup>
3.0	4.25 x 10 <sup>10</sup>	2.9 x 10 <sup>-11</sup>
10.0	1.45 x 10 <sup>11</sup>	9.6 x 10 <sup>-11</sup>
30.0	4.35 x 10 <sup>11</sup>	2.9 x 10 <sup>-10</sup>
50.0	7.25 x 10 <sup>11</sup>	4.8 x 10 <sup>-10</sup>
<b>Neon</b>		
0.1	2.05 x 10 <sup>9</sup>	9.6 x 10 <sup>-13</sup>
0.3	6.15 x 10 <sup>9</sup>	2.9 x 10 <sup>-12</sup>
1.0	2.05 x 10 <sup>10</sup>	9.6 x 10 <sup>-12</sup>
3.0	6.15 x 10 <sup>10</sup>	2.9 x 10 <sup>-11</sup>
10.0	2.05 x 10 <sup>11</sup>	9.6 x 10 <sup>-11</sup>
20.0	4.10 x 10 <sup>11</sup>	1.9 x 10 <sup>-10</sup>
(Data for gases at 298 K)		

$$^a P_b = \frac{2}{3\pi} \left( \frac{r_a}{1} \right)^2 \frac{C_p}{C_a} P_s$$

Table II  
Relationship of source pressure to beam flux and pressure.

scattering of molecules into the inlet was essentially eliminated. Thermo-couples were attached to the mass spectrometer inlet to monitor its temperature. Provision was also made to vary the temperature of the mass spectrometer source inlet using an externally controlled heating element.

The test sequence was basically as follows: The mass spectrometer inlet plenum was initially set at -5° pitch and 0° yaw. The chamber was evacuated and the test chamber wall filled with liquid helium. This reduced the background pressure in the test chamber to the low  $10^{-14}$  Torr region as indicated on a Redhead gage (these gage readings are only an indicator that the chamber is pumping properly and are not used in the molecular beam flux calculations). Background readings were taken on the mass spectrometer. Then the beam source pressure was set at 1.0 psi argon and a minimum of three scans of the argon spectrum was taken on the mass spectrometer. Table II gives the relationship between source pressure and beam flux. After the first set of readings, the source pressure was reduced to zero in order to again make background readings. Source pressures of 3.0, 10.0, 30.0, and 50.0 psi were then set and mass spectrometer scans taken for each reading. Between each pressure point, the source was evacuated to obtain background readings. The data were recorded as ion counts for each peak in the spectrum less the background counts for that peak. The above procedure was repeated for yaw settings of 10°, 20°, 30°, and 40°. After completion of the argon tests, the complete procedure was repeated using neon as the test gas. Source pressure for neon was limited to 30.0 psi due to the fairly rapid background pressure buildup by the neon at higher pressures.

The above tests were repeated for pitch angles of 0° and +5°. Other data were taken for various inlet plenum temperatures between 238 and 300 K, and certain pressure sweeps were repeated using each of the two filaments in the mass spectrometer ion source.

From the above tests, it was possible to make a rather complete evaluation of the performance of the mass spectrometer. The data were analyzed to give comparison of filament performance, establish linearity of the instrument, assess output as a function of pitch and yaw angles, verify the effects of inlet (plenum) temperature variations, and determine the sensitivity of the instruments for the two test gases.

Figure 2 shows the output, in counts/second, of 3 instruments vs beam flux for both argon and neon. The data show the instrument to be linear over the range tested, with any deviation from linearity well within the beam accuracy (6%). The linearity test was extended to several decades using minor isotopes of the test gases. The data are presented in terms of beam flux rather than pressure since the speed ratio of the incoming gas between the calibration beam and actual flight differs by about a factor of 5. The actual equilibrium pressure in the inlet must be calculated for each gas molecule speed (gas temperature or ram velocity in flight). It was found that the sensitivity limit of the instrument to lunar orbital velocity gases was  $10^{-14}$  Torr with an accumulation period of 0.1 sec.

The relative sensitivity of the two filaments on Flight 1 and Flight 2 instruments is of the order of 15% for argon. There is more variation in sensitivity between instruments than there is between filaments in a given instrument.

Figure 3 gives the variation in output for inlet (plenum) temperature variation from 238 to 300 K as measured by the Flight 2 instrument. The variations lie within the relative error bars of the measurements (5%) and are certainly much less than the square root of temperature ratio (12%). This probably results from actual variation of ion source temperature being less than the temperature sensors on the source housing indicated.

The absolute calibrations showed the instrument capable of measuring gases of partial pressures down to  $10^{-14}$  Torr at spacecraft velocity with a linear response over several orders of magnitude. The corresponding sensitivity was  $2.8 \times 10^{-4}$  A/Torr (the counting accumulation period was 0.1 sec). The argon to neon ratio of a factor of 5 is in good agreement with the ionization cross sections for the electron energy used (70 eV). The plenum temperature studies show relative insensitivity to temperature with constant input flux, possibly indicating that the ion source temperature variation was less than the temperature sensors on its housing reported.

Calibration of the lunar surface mass spectrometer for the Apollo 17 ALSEP was performed at the Langley Research Center in a manner similar to that of the lunar orbital mass spectrometers flown on the Apollo 15 and 16 missions. With known beam flux and ion source temperature, instrument calibration coefficients are determined. Variation of gas pressure in the molecular beam source chamber behind the porous silicate glass plug varies the beam flux and provides a test of the linearity of the instrument response. Good linearity was achieved to as high as  $5 \times 10^5$  counts/sec, where the onset of counter saturation occurs.

Calibrations were done using argon, carbon dioxide, carbon monoxide, krypton, neon, nitrogen, and hydrogen. The sensitivity of this instrument was found to be slightly less than the lunar orbital instrument because of its higher mass resolution, necessitating narrower slits. However, with a factor of 6 longer integration period, it was found to have the capability of measuring gas concentrations of  $100 \text{ molecules/cm}^3$ .

While the LACE instrument was calibrated at counting rates up to 1 MHz, improved counters have been developed for the Pioneer Venus mass spectrometer which extend the range to 10 MHz giving a dynamic range of over 6 decades.

Thus with the modifications to the LACE instrument suggested above and the inclusion of a getter, it appears that this mass spectrometer would be suitable for the proposed task of determining the residual neutral gas species in the Large Molecular Wake Shield Space Vacuum Facility.

The status of the Langley Research Center molecular beam chamber over the past two years has precluded the possibility of continued testing of mass spectrometers during that time. However, rather thorough studies were conducted at the time of calibrations of the lunar instruments and there is no reason to suspect that the results could not be duplicated.

The ion mass analyzer is based upon those flown on the ISIS-II and AE-C and D spacecrafts. (Hoffman, et al., 1970a, 1974a). Data from these spacecrafts show clearly an in-flight sensitivity to  $H^+$  ions of approximately 0.1 ion/cc in the ram direction. Ram to wake ratios of light ions are much smaller than the corresponding neutrals, being typically of the order of 10 to 20. For  $H^+$  concentrations of between  $10^3$  and  $10^4$  ions/cc (measured values at the altitudes the Shuttle will fly), the wake concentrations of  $H^+$  will be of the order of  $10^2$  to  $10^3$  ions/cc for a nominal spacecraft potential of -0.5 to -1 volt relative to the plasma potential. Only if the spacecraft potential is made to go positive (a few eV is sufficient) will this wake ion concentration be reduced. For  $He^+$  the ram to wake ratio of a factor of 100 or more implying that  $He^+$  wake concentrations will be of the order of 1 to 10 ions/cc or less. For heavy ions,  $N^+$ ,  $O^+$  and the molecular species ( $N_2^+$ ,  $NO^+$  and  $O_2^+$ ) the ram to wake ratio is as large as 6 decades. Therefore, even in mid latitude daytime regions the  $O^+$  wake concentration should be less than 1 ion/cc. Therefore it appears quite feasible to use a standard ion mass analyzer like those flown several times previously by UTD to determine the ion concentrations in the wake of orbiting vehicles.

The use of chemical getter pumps has been exploited in the Pioneer Venus Neutral Mass Spectrometer instrument that was flown to Venus to measure the composition of its lower atmosphere.

An extremely good vacuum is maintained in the mass spectrometer ion source and mass analyzer by a set of 3 chemical getters (G in Figure 4) and two ion pumps. One getter and pump is attached to the ion source region, another pair to the mass analyzer. The third getter in the IRMC (Isotope Ratio Measurement Cell) is used for removal of reactive gased for the high altitude sample.

In order to maintain a constant pressure in the ion source cavity throughout descent, Getter 1 is located behind a variable conductance valve (VCV in Figure 4) directly in line with the inlet tube on the opposite side of the ion source cavity. The VCV, initially closed with a conductance of 1 cc/sec, is pneumatically opened by increasing atmospheric pressure, thus increasing the conductance to the getter pump, as the atmospheric pressure increases during descent. This increased gas flow rate is balanced by the increased throughput to the pump resulting in a relatively constant ion source pressure. With the VCV fully opened the getter has a pumping speed of nearly 2 liter/sec and a capacity of several times that required to maintain pressure of  $< 10^{-5}$  torr in the ion source cavity.

In addition to the getter, a 2 liter/sec ion pump (Ion Pump 2) is attached to the ion cavity. This pump is controlled by the microprocessor, but it is also activated whenever the analyzer pump current exceeds a fixed threshold.

The ion source cavity and mass analyzer section are separated by a very narrow ion focussing aperture. A pressure differential ratio of up to 700 can be maintained across the aperture by ion pump 2 (2 liter/sec) and getter 2. The small size and weight constraints of spacecraft operations required that special ion pumps be developed at UTD for the mass spectrometer.

Initial evacuation of the mass spectrometer vacuum envelope and associated pumps was done by attaching the instrument to a set of 3 vacuum manifolds, each connected to an ion pump having an 8 or 60 liter/sec pumping rate. The instrument was attached to the manifold system through a set of 5 manual valves. An automatically temperature controlled oven was placed over the instrument and manifolds for bakeout. Chemical getters and the molecular sieve were activated by heating them to a temperature of 250°C for several hours.

The getter pumps worked very well in flight. Pressures in the ion source were maintained at the desired level without the operation of the ion source ion pump. Since these getters are operated at room temperature, it is very straightforward to remove gases from the getters by heating them. Thus the accumulation of wake gases behind an orbiting vehicle using such a getter with a subsequent release for measurement would work very well. Most atmospheric gases except noble gases have been found to respond well to the getter operation.

#### IV. LABORATORY TEST RESULTS

In order to minimize outgassing from the instrument ion source, this portion of the instrument should be operated at as low a temperature as possible. Towards this end a cold electron source is being developed by Spindt at SRI International using new methods of thin-film technology and electron beam

microlithography. Miniature field emission cathodes have been produced in arrays of up to 5000 cathodes packed at densities of up to  $6 \times 10^5 / \text{cm}^2$ .

In order to test the applicability of this cold cathode as a mass spectrometer ion source, several thin film field emission cathodes were obtained from SRI each consisting of an array of submicron-sized solid metal cones on a conducting substrate whose tips are centered in 2 to 3  $\mu\text{m}$  holes in a counter electrode or gate, separated from the substrate by an insulator of silicon dioxide approximately 1  $\mu\text{m}$  thick. The gate is a thin (0.4  $\mu\text{m}$  thick) vapor deposited film of molybdenum on the silicon dioxide. The holes are etched in the film. The cone heights, tip radius, and film aperture size are variables of the fabrication technique that offer some control over the current voltage characteristic. A significant advantage to this type of field emitter is that a potential of 100 to 200V is all that is required to produce an electron beam of hundreds of  $\mu\text{amps}$  that is well collimated. Conventional field emitters using etched wire construction require up to 30,000V to produce useable electron beams. Another advantage of the thin film cathode is its large number of tips, approximately 5000, concentrated in a small area, 1 mm dia. If a few tips become inoperative, the loss of current is not significant, whereas a cathode with a single tip is very sensitive to the tip's condition.

One of the cathodes was mounted in the standard ceramic block filament holder used in our mass spectrometers. This block, approximately 1 x 0.8 x 0.3 cm, contains two heavy pins to which a tungsten filament is normally spot welded. The field emitter cathode contained two leads which were welded to the pins to mount and locate it relative to an aperture in the ion source. The ion source was a standard item of a flight type mass spectrometer attached to a large

ion pumped vacuum chamber. The system was fitted with a leak valve to admit test gases to the mass spectrometer.

Preliminary tests were run with an AC power source connected between the cathodes and gate. It took several hours for the emission current collected by a Faraday cup, placed on the opposite side of the ion source, about 1 cm from the gate, to become stabilized. It then ran rather steadily at an emission current of 150  $\mu$ A for several days. However, after that time the tip to gate became shorted, probably by a whisker having grown from one or more tips to the gate. When a condenser charged to approximately 30V was discharged across the tip-gate junction the short was removed and normal operation was resumed. Such a short developed about once a day for a couple of weeks. When a higher voltage discharge was applied, the short was able to be controlled for much longer periods of time.

Additional tests have shown that when the cathode is operated by a square wave pulse with a duty cycle of up to 50% its output stability is considerably improved and the shorting problem significantly reduced.

An emission regulator was developed to operate the cathode and control its emission by varying the duty cycle (percentage on time) of the applied voltage pulse between cathode and gate. The results of this operation look encouraging.

Mass spectra taken with the cold cathode looked very similar to those taken with the same mass spectrometer using the conventional hot filament ion source. Peak shapes and mass resolution were very good indicating that the energy spread of the ion beam emerging from the source was small.

Studies of the operation of the cold cathode ion source will be continued to determine its response on exposure to various gases from inert gases to

highly reactive gases. Preliminary tests at SRI indicate that the effective work function of the cathode appears to change by exposure to some gases, but to reach an equilibrium with the cathode's environment at a given operating condition. The change in work function by exposure to such gases is completely reversible and non-damaging to the cathode. In this case the response of the ion source should readily be calibratable.

The significant advantages of the cold cathode ion source over a typical hot filament source are low power, the only power used is that to accelerate the electrons; high electron brightness, currents of many millamps can be drawn from the cathode; and low operating temperature. The latter results in very low background peaks compared to those resulting from local outgassing of the source from the heat dissipated by the filament, normally 1 to 2 watts. These advantages would suggest that use of the device as a source for a mass spectrometer for several possible future space missions, including the molecular wake shield study, is warranted.

#### CONCLUSION AND RECOMMENDATIONS

From the evaluation of previous flight instrumentation both for neutral gas composition and ion composition studies, it is quite feasible to assemble an instrument consisting of a dual mass analyzer, one for neutrals and one for ions, to detect, identify and measure the concentrations of gas and ion molecules in the wake of an orbiting vehicle. The mass range 1 to 46 amu would be covered that includes all the normal atmospheric constituents, i.e., hydrogen, helium, neon, nitrogen, oxygen, argon and carbon dioxide. The sensitivity of the neutral gas instrument has been shown to be sufficient to measure directly particle densities of the order of  $10/cm^3$ . An enhancement factor of 10 is possible by employing a chemical getter to accumulate gases for subsequent release by heating the getter. For gases that are readily ad-

sorbed by the getter the density limit will be  $1/\text{cm}^3$ . This includes the major atmospheric gases, except the noble gases.

For ambient ions, the sensitivity determined in flight is of the order of 0.1 to 1 ion/ $\text{cm}^3$ . Therefore it appears that the standard ion mass analyzers, like those flown previously by UTD on the ISIS-II and Atmospheric Explorer space-crafts, will be capable of determining the ion concentrations in the wake of orbiting vehicles.

The dual analyzers would be packaged together with much of the electronics being common. Low voltage power supply, electron multiplier power supply and data handling and compression circuitry could be common to both analyzers. Weight of the instrument package would be approximately 13 kg and power would be of the order of 14 watts. If the cold cathode source were used the power could be reduced approximately 2 watts.

The instrument should have the capability of being handled by the Shuttle's remote manipulating unit. The mount should allow the instrument's entrance aperture to be orientated both towards and away from the Shuttle to detect the direct outgassing flux from the vehicle and the ambient gas density in the wake when the aperture is shielded from this direct outgassing flux.

Since there exists at UTD several flight spare mass spectrometers from previous programs it would be quite feasible to assemble a flight type instrument for a study of the wake of the Space Shuttle. This package could be prepared and tested in the order of a year for a fairly modest cost. Some electronics circuits, particularly those that interface the instrument with the Shuttle systems, would require redesign. It would be possible to interface this instrument with the IECM system that is planned to study the gaseous environment surrounding the Shuttle vehicle.

An estimated cost for the preparation of a flight model is given in Table III.

TABLE III. COST ESTIMATE TO DESIGN, BUILD AND TEST A MOLECULAR VAKE  
SHIELD GAS ANALYZER

CUMULATIVE

I. DIRECT COST

A. Salaries & Wages

1. Senior Personnel

Principal Investigator-John H. Hoffman	\$4,236
Associate Investigator-R. Richard Hodges	4,897.

2. Other Personnel

Professionals

Systems Engineer/Proj. Eng.	\$23,967.
Mechanical Engineer	18,337.
Electronics Eng. A.	21,063.
Electronics Eng. B.	8,914.
Scientific Programmer	9,598.

Technical, Shop, Other

Vacuum Lab Technician	\$18,837.
Instrument Tech.	16,576.
Electronics Tech.	5,401.
Instrument Machinist	7,497.
Detail Draftsman	4,747.
Secretarial/Clerical	5,142.

Total Salaries & Wages	\$149,212.
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B. Fringe Benefits @ 22.6% of S&W                            33,722.

C. Laboratory Supplies    3,000.

D. Instrument Parts/Materials/Supplies                        50,000.

E. Purchased Services-Machinery, Plating, Testing, Welding    8,000.

F. Subcontract-Environmental Testing Services                3,000.

G. Project Equipment-Calib. System/Test/Micro-Develop/GSE    15,000.

H. Equip. Repair, Maintenance, Calibration, Rental            500.

I. Travel Out-of-State    8,000.

J. Travel-Local    1,500.

K. Communications    1,200.

L. Postage, Freight, Special Handling                        1,350.

M. Reproduction, Photo, Copy                                    2,100.

N. Media Services, Data Services                                1,200.

O. Computer Useage    1,750.

P. Page Cost, Pre-prints, etc.                                2,000.

TOTAL DIRECT COST	\$281,534.
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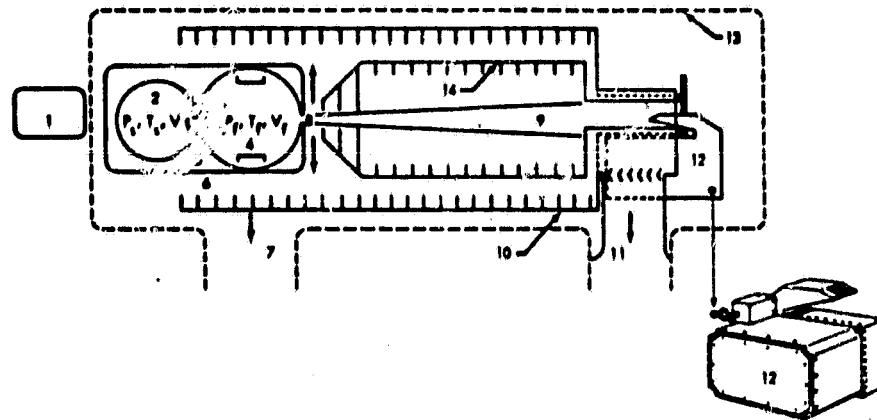
II. INDIRECT COST @ 60% of Salaries and Wages	89,527.
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TOTAL COST	\$371,061.
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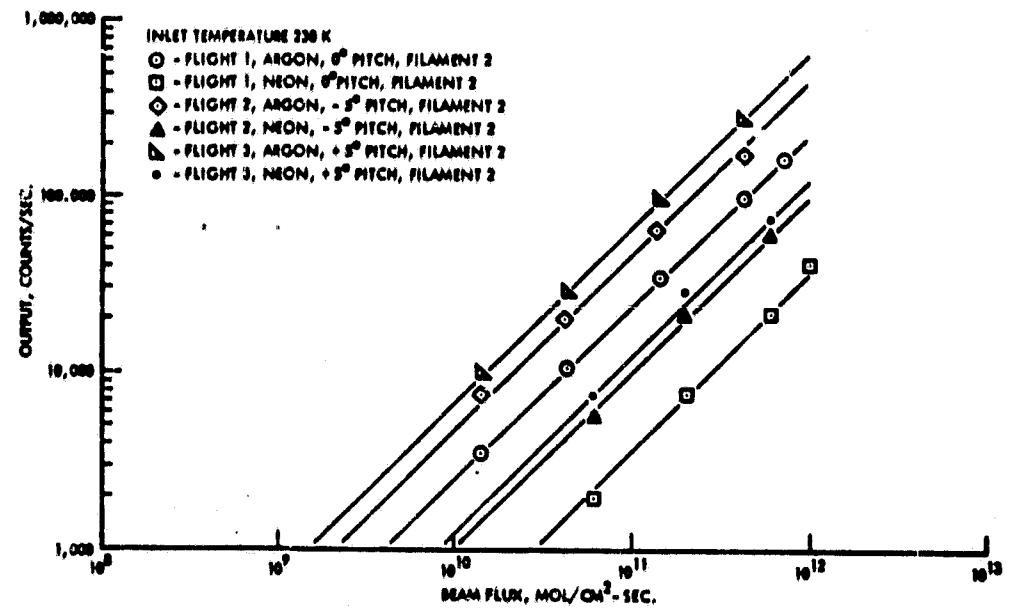
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- 1 Pressure standard
- 2 Pressure source
- 3 Peristaltic pump
- 4 Molecular beam
- 5 Controlled temperature enclosure
- 6 Auxiliary cryopump
- 7 Auxiliary diffusion pump
- 8 Beam aperture
- 9 Molecular beam
- 10 LN<sub>2</sub> liner
- 11 Main diffusion pump
- 12 Mass spectrometer
- 13 Vacuum enclosure
- 14 LN<sub>2</sub> molecular beam cryopump



**Figure 1.**  
**Molecular beam apparatus. Schematic drawing showing the interior of the system and position of the mass spectrometer.**



**Figure 2.**  
Variation of output for neon and argon for three flight instruments

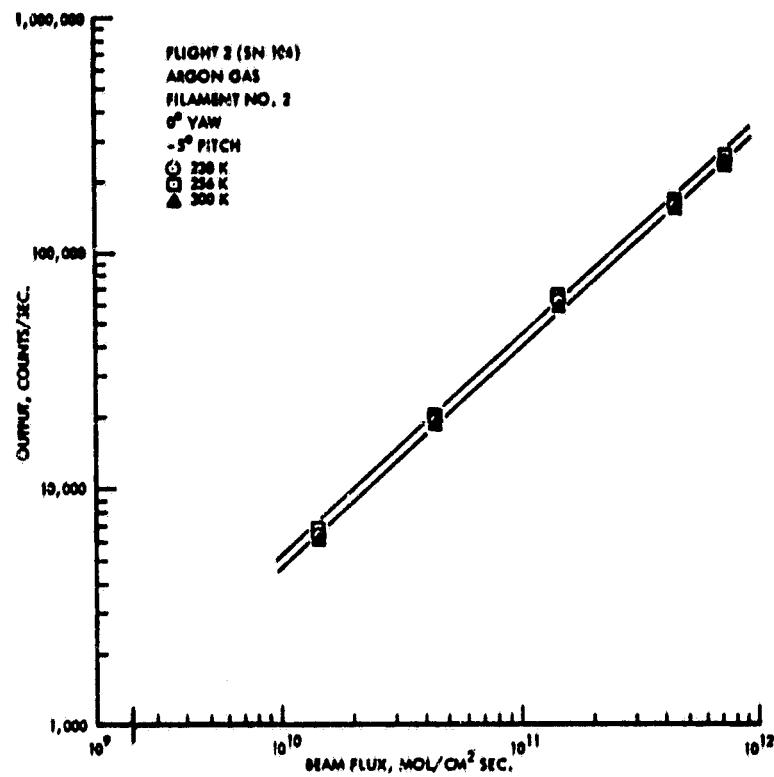


Figure 3.  
Variation in output with inlet (plenum) temperature over the range 238-300 K

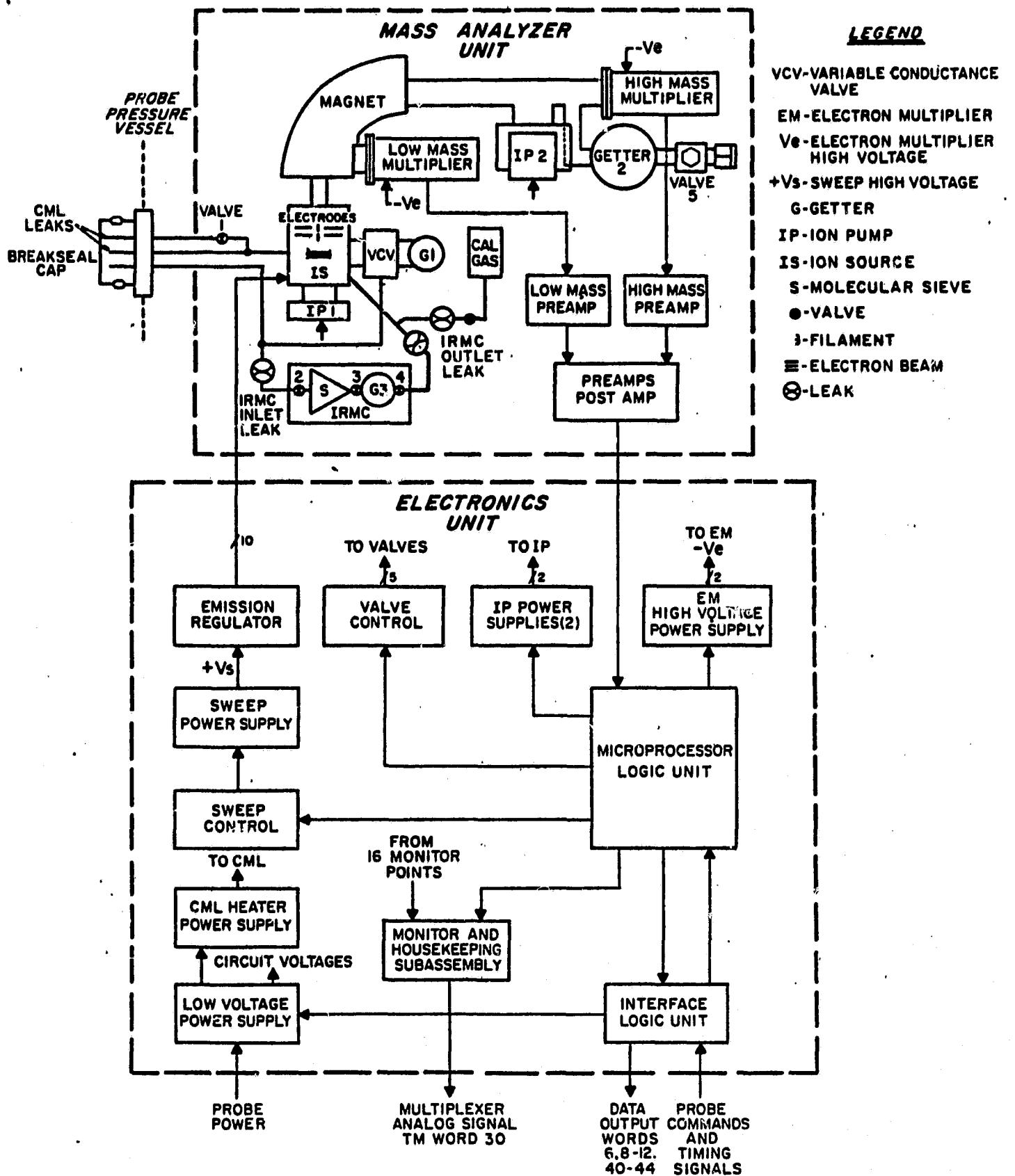


Figure 4